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ONSET AND ADVANCE OF SOUTH-WEST MONSOON ALONG WEST COAST OF INDIA*

A. S. RAMANATHAN

Meteorological Office, Poona

ABSTRACT

The problem of the onset of south-west monsoon over Kerala and its advance along the West-coast has been investigated for the period 1956-1969, making use of the extended charts for the surface and 500 mb. It is shown that the following extra-tropical synoptic features have a strong influence on the onset of monsoon over Kerala and its advance along the west coast.

1. Variations of trough ridge pattern at 500 mb as observed between 40° and 50°N round 60°E (Aral Sea region) during May and June.
2. The nature of monsoon activity over coastal Burma at the time of onset of monsoon over Kerala and during the subsequent period in May and June.

In the light of the above synoptic features, the late and early arrival of monsoon over Kerala, its quick and slow advance along the west coast and its temporary weakening and revival during the months of May and June are examined in detail. The formation of low pressure areas over Arabian Sea and the subsequent intensification of some of them during the months of May and June is also examined and its association with the synoptic features listed above is discussed. A passing reference has also been made to the heavy rainfall over Kerala and coastal Mysore during July 1968 and relevant remarks made on the same.

INTRODUCTION

THE problem of the onset and advance of the south-west monsoon along the west coast has been the subject of investigations by several Indian and foreign meteorologists. Beginning with Eliot (1890) several meteorologists have examined in detail the synoptic features of surface and upper air over India and neighbourhood at the time of onset of monsoon over Kerala. A fairly exhaustive review of the literature is available in one of the issues of *Forecasting Manual* dealing with the 'Synoptic features associated with the onset of monsoon over Kerala' (1968). While many have dealt with the changes that take place in the lower and upper troposphere over India, a few papers deal with the upper and middle tropospheric changes that take place in the subtropical and extra-tropical regions of the northern hemisphere at or prior to the time of the onset of the monsoon over the southernmost part of the west coast of India [Yin (1949), Sutcliffe and Bannon (1954), Yeh Daland Li (1959), Flohn (1960), Koteswaram (1960) Lockwood (1963), Ramaswamy (1965) and de La Mothe and Wright (1969)]. Reference should also be made to Thompson's (1951) essay on the general circulation over south-east Asia and West Pacific in which he has referred to some important changes that take place over south-east Asia at the lower tropospheric levels which have a direct bearing on the onset of monsoon over north Indian Ocean.

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The author has been engaged for some time in a detailed examination of this problem of the onset of monsoon over Kerala, its late and early arrival, its quick and slow advance along the west coast and its temporary weakening and revival during the months of May and June. Certain extra-regional synoptic features which seem to be associated with the above vagaries of the monsoon were examined for a number of years. The results of the study are presented in this paper.

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Resume of Earlier Work

Since the investigation dealing with features which are seen outside the Indian region and which have relation to the onset of monsoon are of relevance in the present context, a brief review of these will be appropriate here. Yin (1949) showed that the so-called burst of the monsoon occurs as a mean low latitude upper air trough is displaced rapidly from one steady position near 90°E to another relatively steady position near 60°E and that the factor that sets the low latitude trough in motion is the northward displacement of the low latitude westerly jet. Sutcliffe and Bannon (1954) demonstrated for the years 1948-1958 a time relationship between first appearance of the easterlies at 200 mb over Aden and Bahrain, the abrupt transition from polar to tropical tropopause over Habbanniya and the onset of monsoon over the west coast of India. Flohn and Koteswaram (1960) stressed the important role played by the seasonal warming of the Tibetan plateau in the circulation features observed over southern half of Asia in summer.

Lockwood (1963) studying the changes in the wind at 200 mb level over the tropics and the subtropics during May and June came to the conclusion that the south-west monsoon reaches the coast of India sometime after the subtropical jet has left India and before the easterlies are established at Khartoum. Ramaswamy (1965) examined the upper air conditions over Asia during years of early and late onset of the monsoon and found that the westerly jet stream plays an important role in advancing or delaying the onset of monsoon over India by its meandering to the north and south of the Himalayas. de La Mothe and Wright (1969) studied the seasonal variations in 16-year average positions of troughs and ridges during the first six months of the year at 500 mb at latitude 50°N and found that the behaviour of the Asian ridge and the wavelength variation across it together with the establishment of a mean trough near 75°E in summer are closely linked with the reversal of wind at 200 mb over northern India and the onset of south-west monsoon over Kerala. However, in the case of a few years they found that the 500 mb circulation patterns played little part in the mechanism of the onset of monsoon, and felt that some other factor, the influence of which is confined to tropical latitudes should be sought for to explain the date of onset of monsoon during these years.

Thompson (1951) has described the major air flow between the surface and 10,000 ft over south-east Asia during the various seasons of the year. Referring to the main features during May, the transition period, he has drawn special attention to the development of south-west monsoon over the Indian ocean. During this period the Indo-China thermal low develops and with this development the upper westerlies over China practically disappear. The Tibetan lee convergence zone at 10,000 ft of the winter season disappears and the Siberian air comes into contact directly with

trades at that level giving rise to the intensification of the west Pacific polar front. In the opinion of Thompson the development of the equatorial trough over north Indian Ocean at 2000 ft, which ushers in the south-west monsoon has a close connection with the internsification of the west Pacific polar front and the Indo-China low. Ruling out the possibility of southern hemisphere origin for the south-west monsoon, he thinks that it is largely a development from the equatorial westerlies observed all the year round at 10,000 ft and that it does not spread from west to east but develops more or less concurrently with the equatorial regions. As a result of the intensification of the west Pacific Polar front and the more northward development of the low over Indo-China, monsoon rains occur earlier over China and Burma than over India. Thompson also drew attention to the fact that in the early part of May trades sometimes continue zonally across Philippines towards the Indo-China low contacting the developing equatorial westerlies at the equatorial North Pacific trades discontinuity, giving rise to the appearance of China Sea trough on synoptic charts. In this trough development of tropical storms take place in the same way as cyclones develop during this season in the North Indian Ocean in the region of discontinuity with westerlies to the south and easterlies to the north.

From the above brief review it will be seen that whereas a majority of workers have sought to link the onset of monsoon over west coast with upper and middle troposphere features occurring in the middle and subtropical latitudes, north of India, Thompson alone has stressed the importance of certain synoptic features in the lower tropospheric levels occurring over south-east Asia and adjoining regions at the time of onset of monsoon over west coast of India.

Data used in the Present Study

Our aim in this study as stated earlier, was to examine the synoptic features observed outside the Indian region not only at the time of onset of the monsoon over Kerala, but also during the period of May and June when the performance of the monsoon over the west coast of India exhibits several interesting features that are of vital importance to the operational forecaster. We have chosen the period 1956-1969 for our study. The charts and data used for our study were the following :

1. Extended charts for surface and 500 mb prepared by the Japan Meteorological Agency (1959-69).
2. Northern hemisphere charts for surface and 500 mb prepared by U. S. Weather bureau (1956).
3. Surface charts of south-east Asia prepared by Vietnam Meteorological Service (1956-58).
4. Täglicher Wetterbereicht (1957).
5. Extended charts prepared and analysed by the Indian Ocean Southern Hemisphere Analysis Centre, Poona (1966-69).
6. Extended charts prepared by the International Meteorological Centre, Bombay (1963-65).
7. Indian daily weather Charts of Weather Central, Poona.
8. Rainfall data for the west coast stations for May, June and July (compiled by Hydrology division of Meteorological Office, Poona).

After a careful examination of the 500 mb charts of northern hemisphere and extended surface charts, we found that the two following extra regional synoptic features have intimate association with the onset of the monsoon over Kerala and its performance, along the west coast during the month of May and June.

1. Variations of trough-ridge pattern at 500 mb as observed between 40° and 50° round 60°E (Aral Sea region).
2. The nature and region of weather activity over China associated with the intensity and position of the west Pacific polar front and the nature of weather activity over Burma at the time of onset of monsoon over Kerala and during the subsequent period in May and June.

Since it is well known that monsoon rains occur over China and Burma before the onset of south-west monsoon over Kerala, it will not be unreasonable to conclude that monsoon will not set in over Kerala unless rains have already commenced over China and Burma. But then the real point for discussion is that in some years even though monsoonal rains have commenced over China and Burma at the normal time, the monsoon over Kerala is delayed sometimes by even ten or twelve days after the normal date. On the other hand there have been years when the monsoon over Kerala sets in the middle of May itself, soon after the first monsoonal rains have occurred over China and Burma. This is one aspect of the problem. Again there have been years when the monsoon sets in over Kerala in the middle of May, advances rapidly northwards along the west coast or recedes completely from the Indian region after a few days to return only after some time say round about or after the normal date. In the month of June, again we get spells of very weak monsoon activity over the west coast in some years whereas in some years the activity in the month of June is practically uninterrupted. We have not come across in the existing literature satisfactory explanations (Malurkar's explanations have not been substantiated by later observations) for the abovementioned features of monsoon activity over west coast in the months of May and June. It is for this reason we examined in detail on a day-to-day basis the two extra regional synoptic features listed in the previous paragraph.

Method of Study and Discussion

In Fig. 1, we have represented the three-day running mean of the contour value at 500 mb at 60°E and 40°N-45°N (Curve A, contour heights at 40°N and 45°N have been averaged) for the period covering the major portion of May and the whole of June for the years 1956-69. Three-day running mean of the contour values at 50°N-60°E for the same period is also represented in the same graph (Curve B) just to distinguish between troughs which penetrate upto or even south of latitude 40°N and those that affect only latitudes 50°N and eventually north of it also. However, the discussion that follows pertains only to Curve A. Against each of these 14 curves we have also given a rainfall diagram which shows the daily rainfall amounts (expressed in code numbers) for twelve selected stations along the west coast *viz.* Trivandrum, Cochin, Alleppey, Kozhikode, Mangalore, Hanover, Vengurla, Ratnagiri, Hernai, Colaba, Dahanu and Surat for the period May-June. These stations reasonably represent the west coast latitudes from 8°N to 21°N.

It may be pointed out here that every fall of the height value in the curves does not necessarily mean the presence or passage of a trough at the longitude under reference, on the days of such occurrence. The weakening of a ridge can also give

rise to fall of contour values. In each curve, therefore, those parts which correspond to passage or presence of trough are indicated by shaded rectangles at the top of each figure. This was ascertained after examining the 500 mb flow pattern for every day of the months of interest for the whole period 1956-69.

In Table 1, we have assembled details regarding the date of commencement of first monsoonal rains over Kerala, synoptic features associated with this commencement and nature of weather activity over coastal Burma and Bay islands. The last column gives details about the subsequent performance of the monsoon.

An examination of Fig. 1 and details given in Table 1 reveals the following :—

1. Monsoonal rains commenced over Kerala in the third week of May or before in ten out of fourteen years.

2. In nine out of these ten years *viz.* 1957, 59, 60, 61, 62, 63, 65, 67 and 69 the early advance was associated with the development of depression or cyclonic storm in the Arabian Sea or Bay of Bengal.

3. In the years 1957, 59, 63, 65, 67 and 69 the advance was not maintained subsequently. Monsoon revived again only after a few days. On the other hand in the years 1960, 61, 62, the monsoon was maintained subsequently, though in the case of 1962 it weakened considerably during the end of May and beginning of June and continued to be so during most of the days of June.

4. In the years 1957, 59 and 63 monsoon had not advanced into the Bay of Bengal and monsoonal rains had not commenced over Burma at the time of commencement of first monsoonal rains over Kerala. In the years 1965, 67 and 69, however, there was a depression or cyclonic storm in the Bay of Bengal and the advance of the monsoon over Bay of Bengal and Andaman Sea and subsequently over Kerala was influenced by it. There was moderate weather activity over Bay islands and coastal Burma at the time of commencement of first monsoonal rains over Kerala though in the year 1969, there was very little activity over coastal Burma.

5. When the monsoon revived over Kerala in the years 1957, 59, 63, 65, 67 and 69, it was active to vigorous over Burma coast.

6. In all the other years, 1956, 58, 60, 61, 62, 64, 66 and 68, Burma coast and Bay islands had good monsoon activity at the time of commencement of first monsoonal rains over Kerala.

7. In all the years except 1962, at the time of commencement of first monsoonal rains over Kerala there was a ridging of contours at 60°E 40°N-45°N (see Curve A). In the year 1962, the monsoon advanced on 14th May in association with a depression in the Bay of Bengal, which emerged into the Arabian Sea near Mangalore on the 18th, when there was a well marked ridge at the longitude of interest (60°E) between 40°N and 45°N.

8. During the year 1958, in which the onset of monsoon was abnormally delayed a series of deep troughs affected the longitude 60°E between 40°N-50°N. Only after 10th June a well marked ridge appeared over that region. Monsoonal rains commenced over Kerala only on the

TABLE I

Year	Date of commencement of monsoonal rains over Kerala	Synoptic features if any observed off Kerala coast or in Bay of Bengal at the time of commencement of rains over Kerala	Nature of monsoon activity over coastal Burma and Bay islands at the time of monsoonal rains over Kerala	Remarks
1	2	3	4	5
1956	18-5-1956	A trough of low pressure off the Kerala coast.	Good	During this year in the second half of May very abnormal conditions existed in the flow pattern at 500 mb. The anticyclonic belt shifted by more than 5° northwards of its normal position so that in the third week of May we had an anticyclone at 500 mb over west Pakistan and adjoining Iran, which takes place only in the second half of June. The monsoon advanced rapidly northwards along the west coast and reached Bombay by the end of May.
1957	18-5-1957	Well marked trough of low pressure in south-east Arabian Sea. It became well marked, moved towards coastal Mysore intensified into a depression and emerged into Arabian Sea on 25th.	Monsoon had not set in	The advance of the monsoon was not maintained. The monsoon revived only on 30th May and at that time monsoonal activity over coastal Burma and Bay islands was good.
1958	14-6-1958	Trough of low pressure in the east Arabian Sea off Kerala and Mysore coasts.	Active	The monsoon advanced rapidly northwards along the coast and its performance during the rest of the month was good.
1959	17-5-1959	A low pressure area developed over south-east Arabian Sea and intensified into a depression on 19th and later into a cyclonic storm.	Monsoon had not set in	The monsoon rains decreased rapidly in the last week of May. It revived again on 29th of May. At that time monsoon activity over coastal Burma and Bay islands was very good.
1960	14-5-1960	A severe cyclonic storm developed in the south Arabian Sea.	-do-	The storm moved away west-northwestwards. A trough of low pressure developed on 21st of May in the south-east Arabian Sea off Kerala and Mysore coasts and monsoon strengthened over

1	2	3	4	5
				Kerala and advanced into Mysore. Monsoon activity over coastal Burma and Bay islands was very good at that time.
1961	19-5-1961	A trough of low pressure developed and persisted over south-east Arabian Sea from 17th to 22nd and rapidly intensified into a cyclonic storm on 23rd.	Moderately active	Monsoon advanced northwards along the coast and its performance during the rest of May was good.
1962	14-5-1962	A depression developed over south Bay and moved across south peninsula and emerged near Mangalore on 18th.	Good	Even after the movement of the depression monsoon was maintained but weakened considerably towards the end of May and the first half of June.
1963	19-5-1963	A low moved into south-east Arabian Sea from the south and concentrated into a depression on 18th and a cyclonic storm on 21st.	Monsoon had not set in	The monsoon was not maintained. It revived on 4th June. Vigorous monsoon conditions existed over coastal Burma and Bay islands at that time.
1964	5-6-1964	A trough of low pressure off Kerala coast which moved northwards and concentrated into a depression on 9th.	Good	Monsoon advanced rapidly northwards under the influence of the depression off south Konkan coast.
1965	19-5-1965	A well marked low pressure area over central parts of the Bay of Bengal which intensified into a depression on 26th.	Moderately active	The monsoon was weak till 4th June. It revived on 5th June. Vigorous monsoon conditions existed over Burma coast on that day.
1966	2-6-1966	A trough of low pressure shifted westwards into Arabian Sea.	-do-	
1967	13-5-1967	A well marked low moved across Maldives and Comorin area.	Moderately active (under the influence of a cyclonic storm in the Bay of Bengal)	The advance of the monsoon was not maintained. It revived on 9th June. At that time monsoon was active over Burma coast.
1968	7-6-1968	A trough of low pressure developed off Kerala and Mysore coasts.	Good	
1969	14-5-1969	A low pressure area developed into a depression in Central parts of Bay of Bengal on 14th May and intensified into a cyclonic storm on 16th.	Monsoon weak over coastal Burma and moderate over Bay islands	Monsoon weakened considerably on 18th. It revived on 25th May. At that time monsoon activity over Bay islands and Burma coast was good.

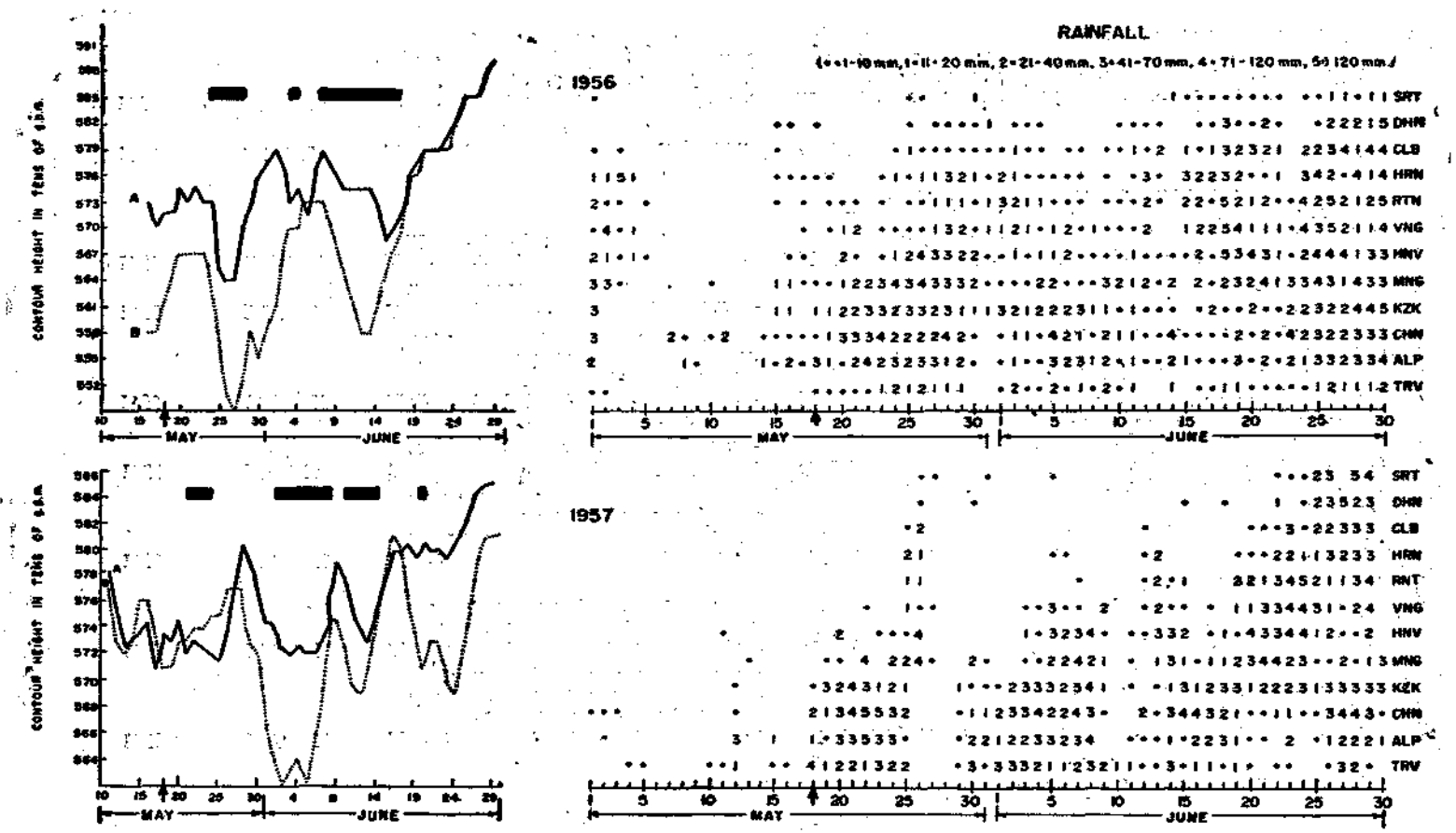

Fig. 1-a. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is also shown against each curve.

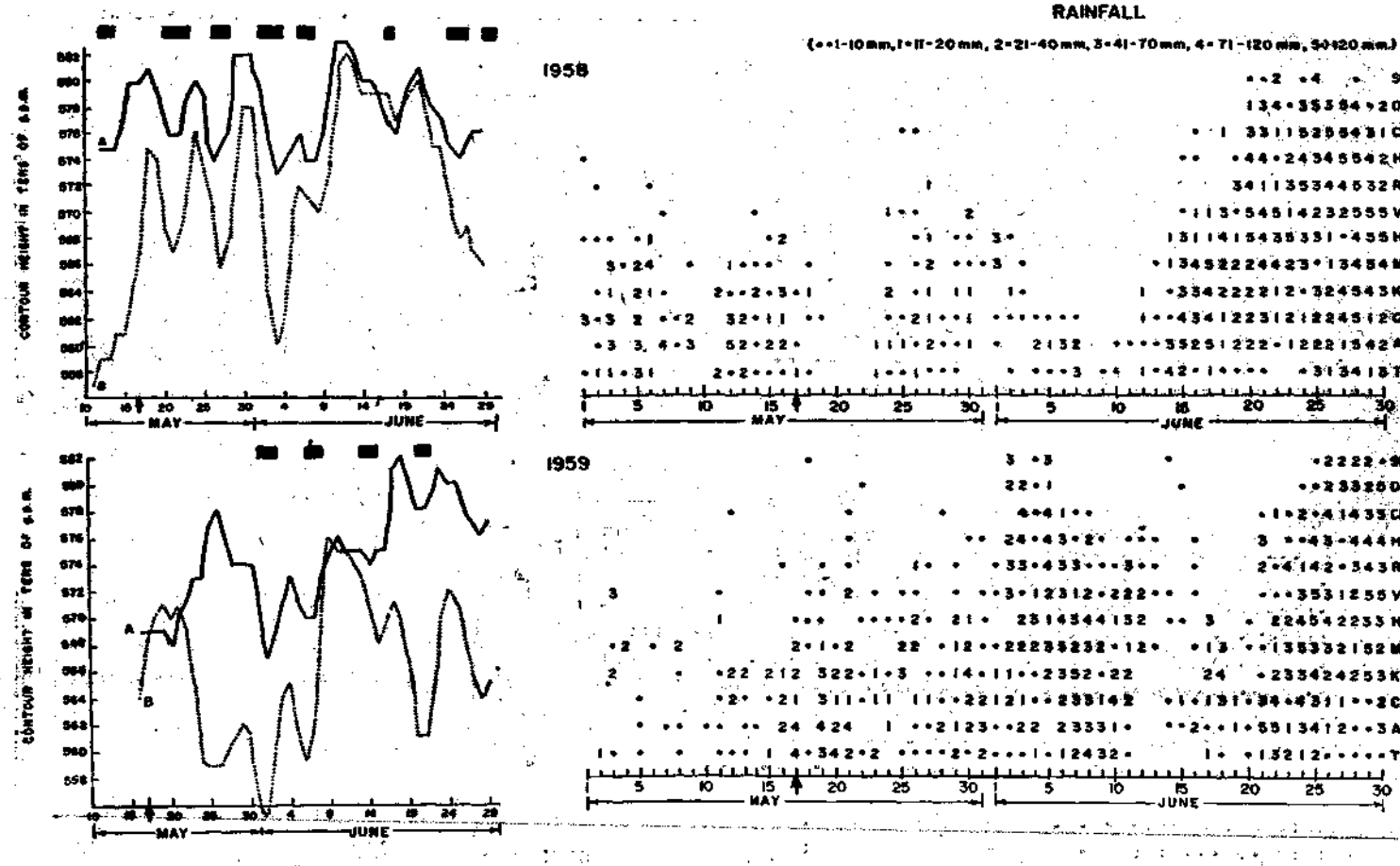

Fig. 1-b. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is shown against each curve.

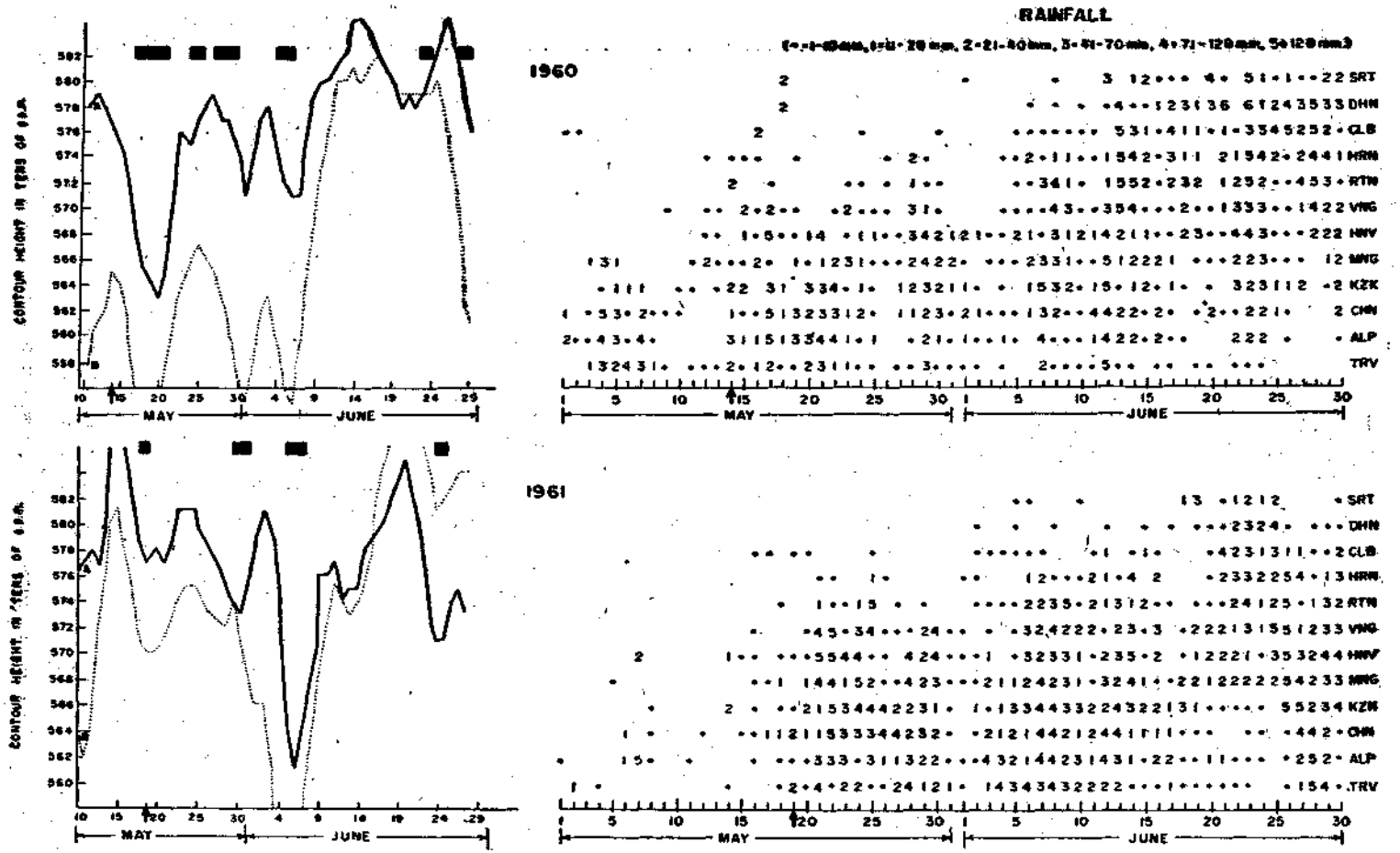

Fig. 1-c. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is also shown against each curve.

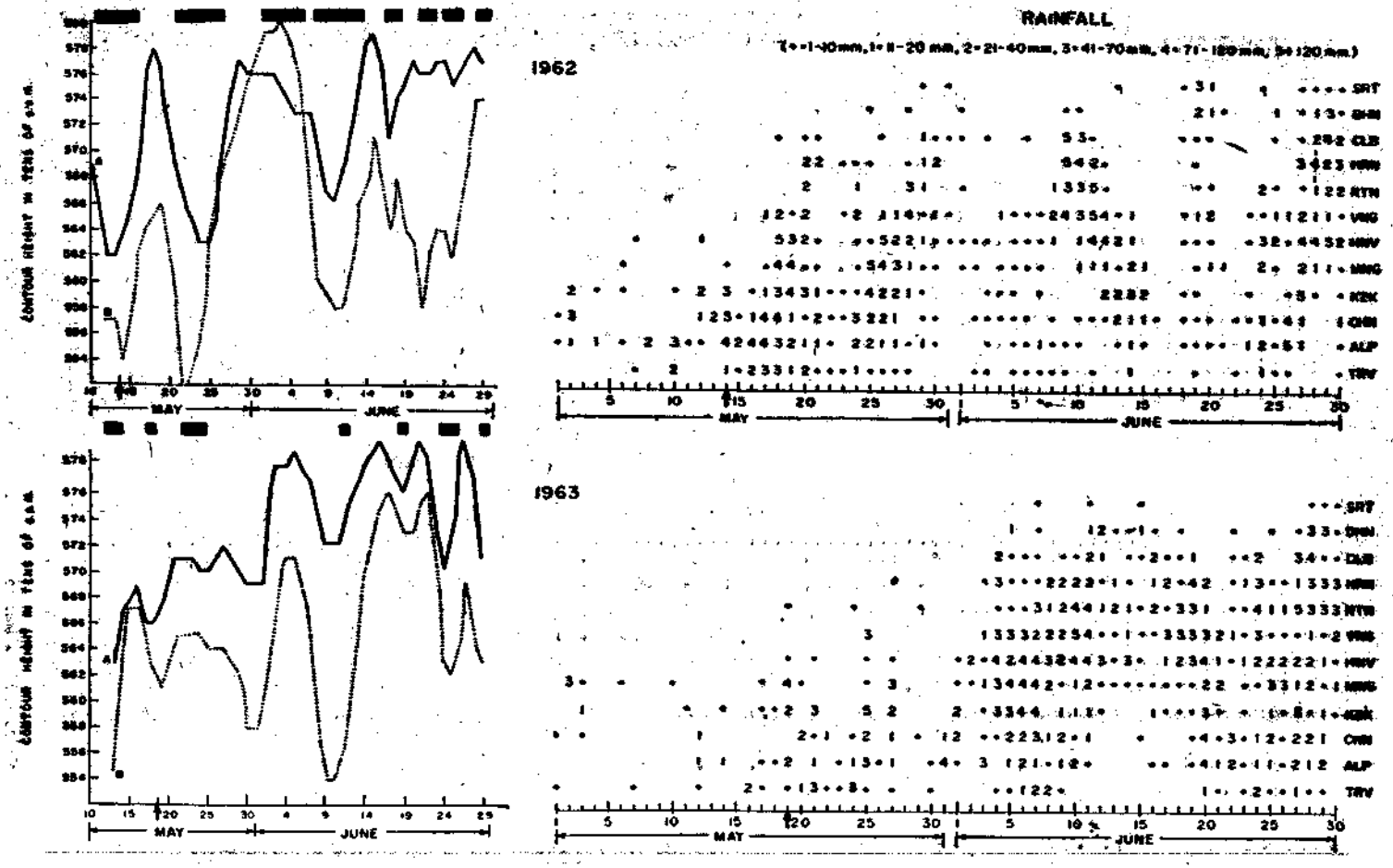

Fig. 1-d. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 30°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is also shown against each curve.

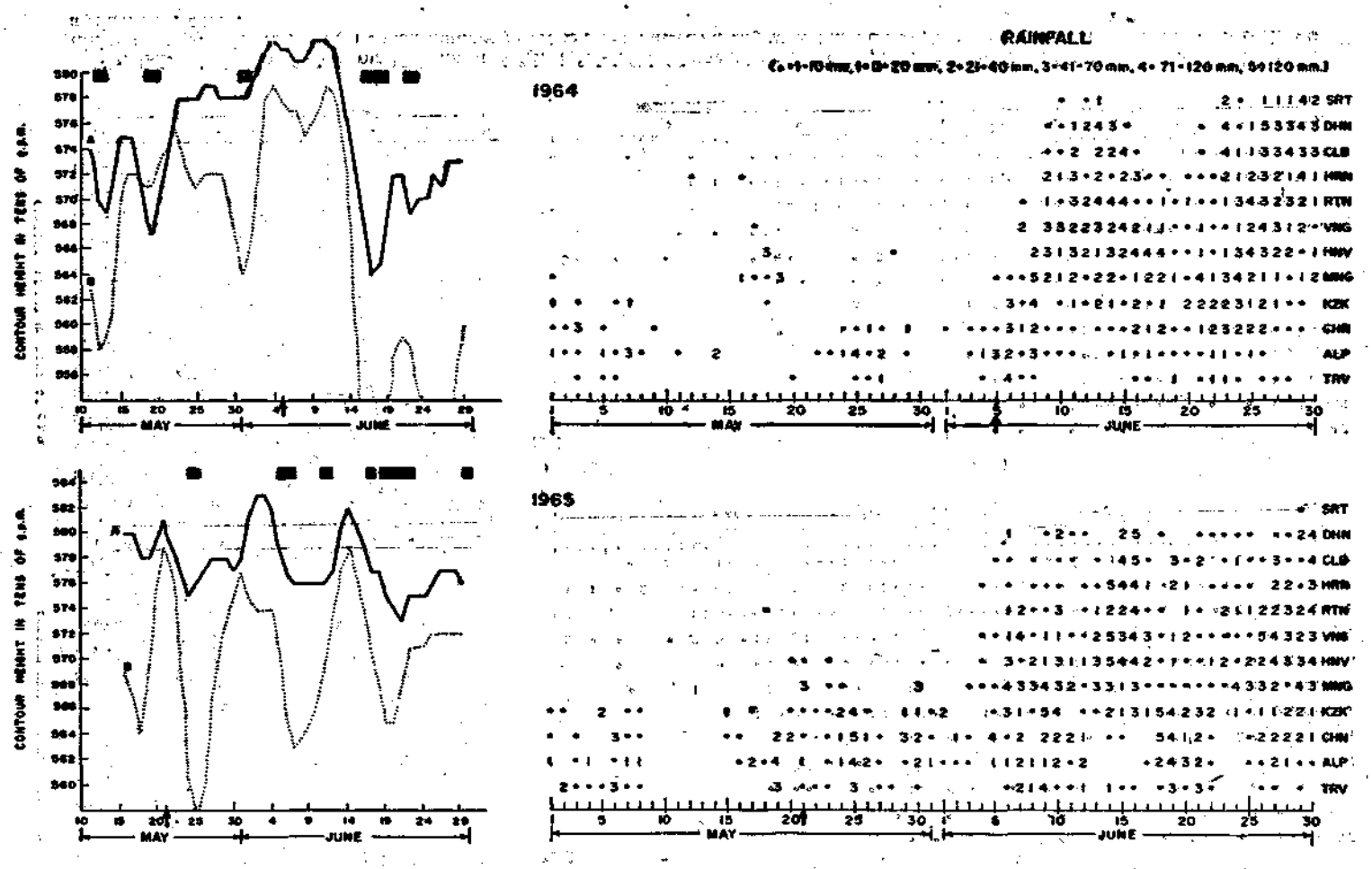

Fig. 1-e. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is also shown against each curve.

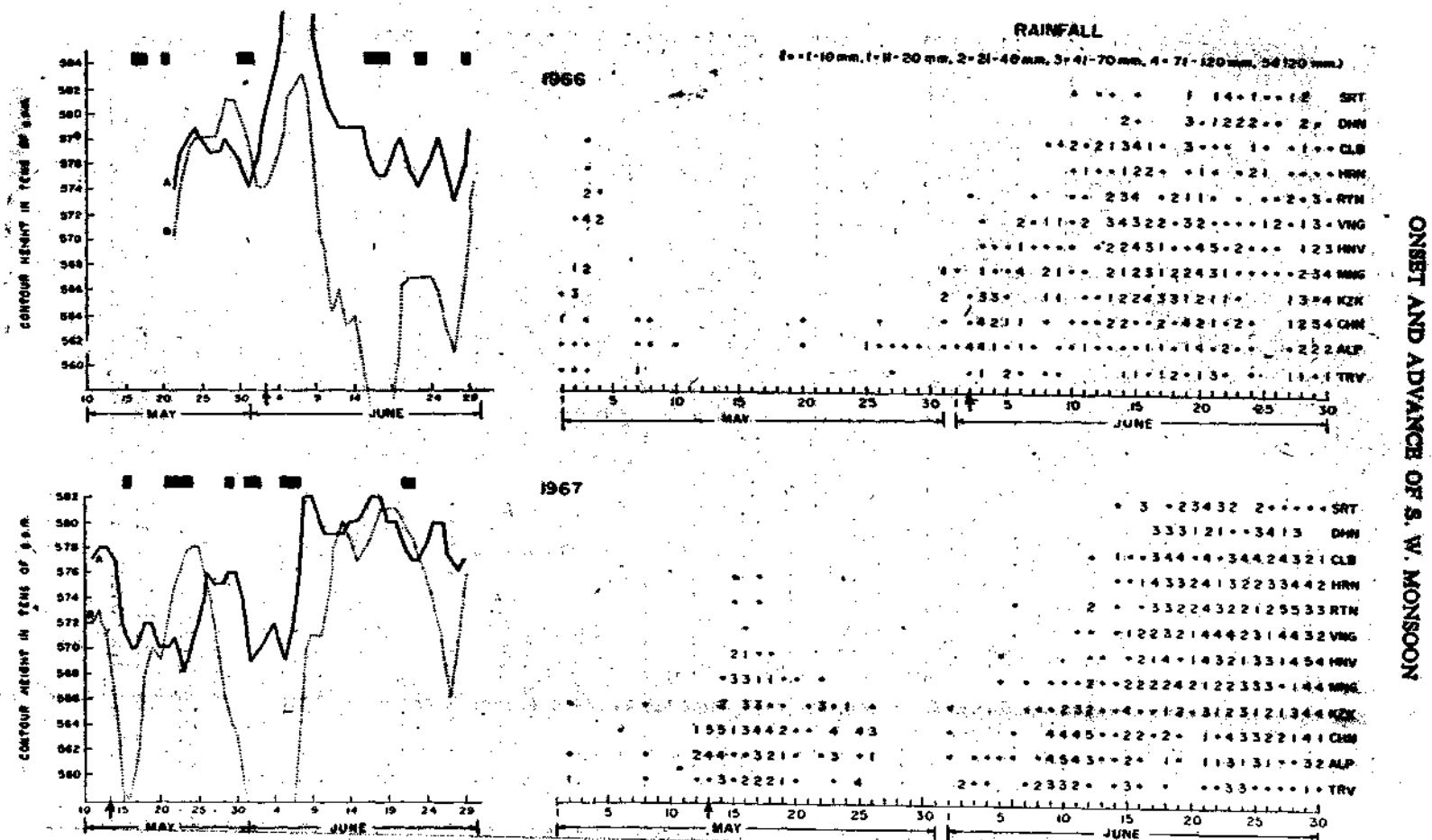

Fig. 1-f. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N (Curve B) at 500 mb during May-June for different years. The rainfall (in coded numbers) over selected stations along west coast during the same period (May-June) is also shown against each curve.

14th of June even though monsoon was quite active over coastal Burma and Bay islands from the 1st of June itself.

9. During the year 1968 between 20th and 26th May, there was a well marked ridge at 60°E, (40°N-50°N). There was no monsoon activity over Burma at this time. Monsoon advanced over Kerala on the 7th of June when (1) there was monsoon activity over coastal Burma and (2) when there was slight ridging of contours at 60°E and 40°N-50°N. However, on 8th, 9th and 10th there was shallow troughing of contours at this place but it did not exist at 50°N (see Curve B).

10. During the years 1959, 63, 65, 67 and 69 the monsoon weakened after its first advance and only after some days it revived over Kerala. When it revived there was ridging of contours at 60°E between 40°N-50°N except in the year 1965.

11. During the major period of June, there was a well marked ridge at 60°E (40°N-50°N) during the years 1956, 58, 60, 61 and 67. During these periods the monsoon activity over Burma coast was very good. The performance of the monsoon over west coast was very good during these periods.

12. In the year 1962 during June on most of the days there was a trough round 60°E (40°N-50°N). During this period even though the monsoon over coastal Burma was good the monsoon over west coast was weak on most of the days.

From the above observations it would appear that the advancement of the monsoon over Kerala takes place sometimes in association with the depression or cyclonic storm in the Arabian Sea or Bay of Bengal and sometimes with a trough of low pressure over Kerala coast. The necessary conditions for the same appear to be (1) monsoon should have already advanced over coastal Burma and should be at least moderately active there. (2) There should not be a trough at 60°E (40°N-50°N) at 500 mb. If a ridge is present it is most favourable. It is worth mentioning here that a well marked ridge was present at 60°E (40°N-50°N) at this level when monsoon advanced over Kerala on the 26th of May during the year 1970. (3) If this ridge remains well marked for a number of days after the setting in of the monsoon over Kerala (as in the case of 1956, 58, 61, 64 and 70) the advance of the monsoon northwards is fairly rapid provided monsoon continues to be at least moderately active over coastal Burma.

Our above findings prompt us to go further into details. Let us examine some more specific periods during which monsoon activity was either very weak or very strong and see how far they can be explained in the light of our findings.

A. During the following periods there was a persistent troughing of contours round 60°E between 40°N-50°N.

1. 7th-17th June 1956.
2. 2nd-14th June 1957.
3. 24th May-1st June 1969.

During the above periods even though monsoon activity over Burma was very good the monsoon activity over west coast was very much below normal. However,

in 1957, the decrease of rainfall occurred only in the latter half of the period under reference.

B. A deep trough persisted round 60°E between 40°N and 50°N for five days between 15th and 19th June in 1964 and between 19th and 23rd June in 1965 and between 14th and 18th June 1969. During these periods the rainfall activity in the northern stations of the west coast rapidly decreased.

C. During the period 12th-20th June in 1959 the monsoon activity over west coast was very weak. In this period there was no well marked trough at 60°E between 40°N-50°N. On the other hand monsoon was very weak also over coastal Burma, during this period.

D. During the following periods of the latter half of June there was very good monsoon activity in the northern stations of the west coast and there was very little activity over Kerala:

1. 17th-21st June 1960.
2. 25th-29th June 1960.
3. 20th-25th June 1961.
4. 12th-19th June 1963.
5. 27th-30th June 1964.
6. 17th-20th June 1967.

During the above period, there was ridging of contours at 60°E between 40°N-50°N the ridging being very well marked in most of the cases.

From the above findings it would appear that persistent trough around 60°E between 40°N-50°N towards the end of May and the first half of June, are unfavourable for monsoon activity over the west coast. Also whenever deep troughs move slowly across 60°E around Aral Sea in the latter half of June, they have a tendency to shift the rainfall belt southwards and the activity of the northern stations decreases rapidly. However, quick moving troughs and shallow troughs do not seem to have any perceptible effect. Again whenever well marked ridges appear round 60°E between 40°N and 50°N in the latter half of June they have a tendency to confine the rainfall to the northern stations and rainfall over Kerala decreases.

The importance of trough ridge pattern round the Aral Sea area for the rainfall over west coast during the month of May and June is enhanced by the fact that whenever low pressure areas formed during this period in the Arabian Sea off west coast there was ridging of contours at 60°E round Aral Sea. Also whenever some of these low pressure areas intensified into depressions or cyclonic storms there was a ridging of the contours at 60°E between 40°N-50°N. Table 2 gives details of these cases.

It is well known that sometimes very heavy rainfall takes place during the end of June or beginning of July over Kerala or coastal Mysore. The synoptic situations responsible for such heavy falls are not often easy to identify over the regions of heavy rainfall. This has been examined by us and a separate note will be published elsewhere on this subject. However, it may not be irrelevant here to mention that the following sequence of events seems to take place on these occasions.

1. Before the heavy falls (over Kerala or coastal Mysore), there is uniformly good rainfall over most of the west coast covering Kerala to Bombay and the rainfall activity over Burma is good.

TABLE 2

Date	Details of formation of low pressure area	Synoptic situation at 500 mb level 60°E (40°N-50°N)	Remarks
26-5-56	Low round 20°N, 69°E	Ridging of contours	This concentrated into a shallow depression on 27th ridging of contours continued.
18-5-57	Low over south-east Arabian Sea	-do-	
7-6-57	Low off Mysore coast near 14°N, 75°E	-do-	
25-6-57	Low near 19°N, 70°E	-do-	
14-6-58	Low near 15°N, 72°E	Blocking high	
17-5-59	Low over south-east Arabian Sea	Ridging of contours	This intensified into a depression on 19th and into a cyclonic storm on the next day near 13°N, 69°E. Ridging of contours continued.
25-6-59	Low off Maharashtra coast	Blocking high	
17-5-61	Low over south-east Arabian Sea	Ridging of contours	This moved northwards and intensified into a cyclonic storm on 23rd when there was ridging of the contours.
21-6-61	-do-	-do-	
9-6-63	-do-	Zonal flow	
21-6-63	Low off Mysore coast near 14°N, 72°E	Ridging of contours	
6-6-64	A trough of low off Mysore coast	-do-	Moved northwards and intensified into a depression on 9th and into a severe cyclonic storm on 10th when there was ridging of contours.
21-6-67	Low near 20°N, 64°E	Blocking high	
29-6-67	Low near 21°N, 66°E	Zonal flow.	

2. At the time of heavy falls, a trough moves across 60°E between 40°-50°N at 500 mb level. The rainfall over northern stations decreases rapidly.

3. As soon as the trough moves away from 60°E heavy rainfall stops and the rainfall belt moves rapidly northwards.

Fig. 2 shows a typical case that occurred in July 1968.

A Possible Physical Interpretation

The onset of monsoon over Kerala is associated in most of the years with the development of either a depression or storm in the Arabian Sea or a trough of low pressure off Kerala coast. The movement of troughs and ridges in middle latitudes across a particular longitude can result in the north-south oscillations of the subtropical ridge at the middle and upper tropopsphere over the Arabian Sea and this can give rise to north-south shifts in the region of development of cyclonic activity south of the subtropical ridge (see for example normal stream line charts of Raman and Dixit for 700 and 500 mb for May). From our results, it would appear that the presence of a ridge round 60°E in the latitude belt 40°N-50°N is favourable for the northward shift of the region of development (can we call this ITCZ ?) and therefore, if other conditions, like the monsoon activity over Burma coast, are favourable there is a possibility of monsoon setting in over Kerala during this period even it be middle of May, if this ridge persists for a few days. On the other hand if there is a persistent trough round 60°E and 40°-50°N during the second half of May and first half of June, the subtropical ridge over the Arabian Sea in the middle troposphere is likely to be south of the normal position and, therefore, it may result in delayed onset and staggered advance over the west coast. As regards the connection between the monsoon activity over Burma coast and that over west coast, it should be emphasised here that both seem to be connected with the activity of the west Pacific Polar front. That such a connection exists was pointed out by Thompson in his essay on the circulation features over south-east Asia and adjoining west Pacific. A careful examination of extended charts and satellite pictures seem to show that such a connection does exist. However, this calls forth a separate detailed investigation. A satellite picture which reveals the close connection between the activity of west Pacific Polar front and the rainfall activity over Burma coast on the one hand and relation between monsoon activity over Burma coast and that over west coast on the other at the time of onset of monsoon in 1968 is shown in Plate I.

Conclusion

The above findings which are based on fourteen years data, in the opinion of the author are of considerable help to the forecaster in forecasting the onset and advance of the monsoon over west coast. In fact if monsoon rains have commenced over Kerala and are not associated with a depression or storm in the Arabian Sea and if immediately afterwards a trough is likely to move more across 60°E near Aral Sea, the rains are likely to decrease considerably and may even completely stop if it is in the middle or even the latter half of May. Again if monsoonal rains have not commenced over Burma and if the setting in of the monsoon over Kerala is associated with a depression or storm over southeast Arabian Sea, then the monsoon is not likely to be maintained unless before the cessation of the rains associated with the storm, monsoon sets in over Burma and no troughing takes place at 60°E, 40°N-

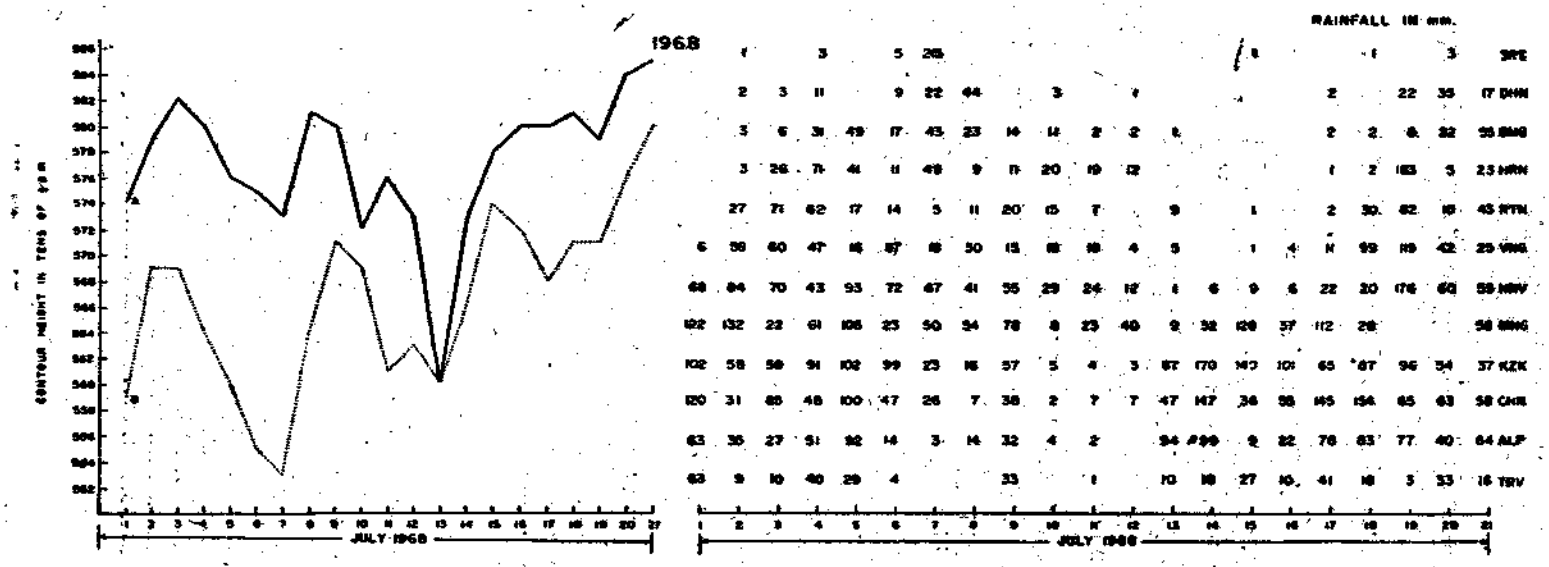

Fig. 2. Variation of Contour Heights at 60°E, 40°N-45°N (Curve A) and at 60°E, 50°N at 500 mb in July 1968. The rainfall for selected stations in the west coast for the same period is also shown in the diagram. Heavy rainfall over Kerala and coastal Mysore occurred at the same time of passage of the Troughs.

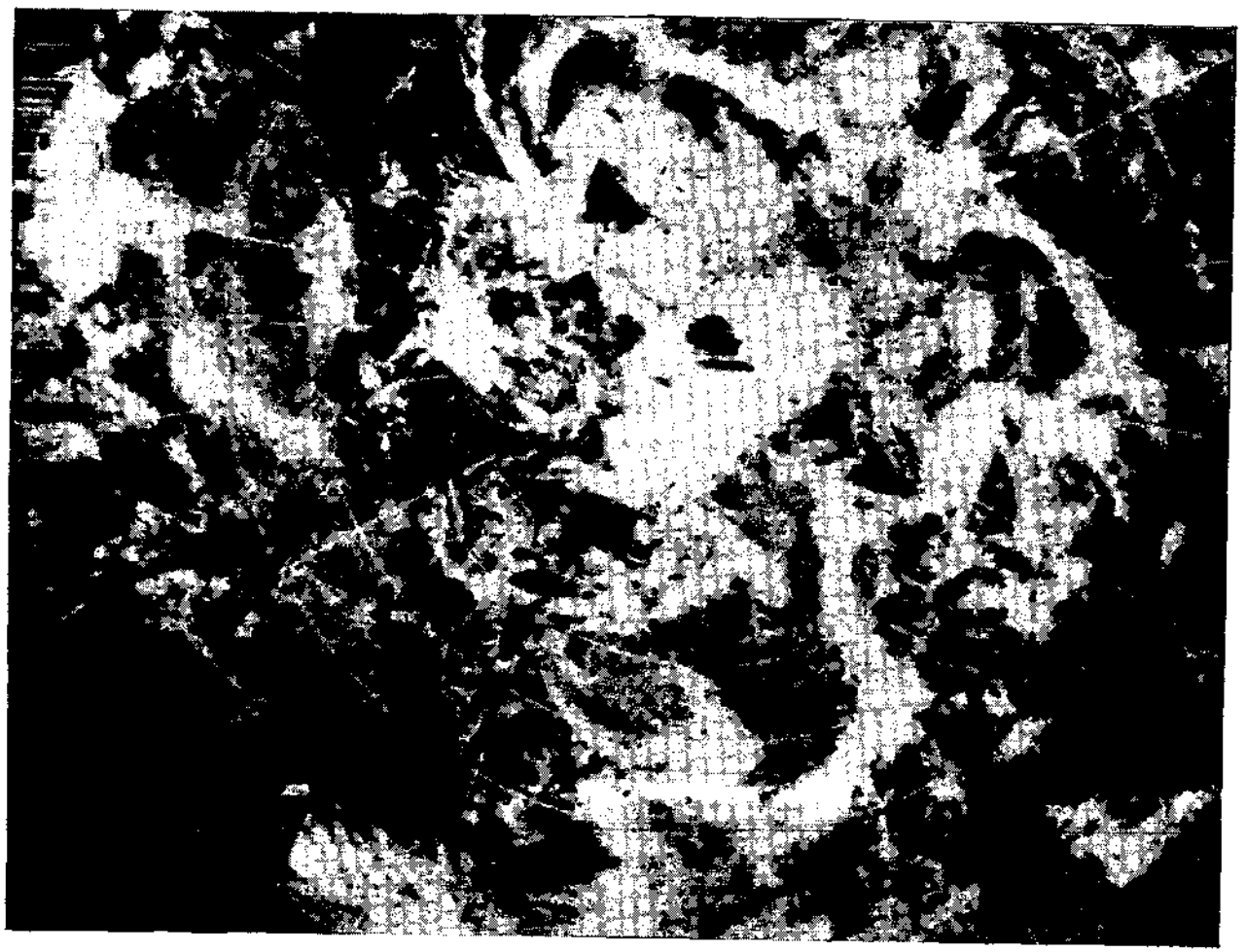

PLATE I. Hemispherical representation of clouds as viewed by the ESSA-3 and 5 Satellites on 9-6-1968. The monsoon set in over Kerala on 7th June. The activity of the West Pacific polar front may be clearly seen in the picture (Picture from ESSA Publication).

50°N. The advance of the monsoon northwards after it has set in, is again affected, as we have seen, by the trough ridge pattern at 60°E round Aral Sea. Thus our investigation seems to offer a plausible explanation for the vagaries of the monsoon over west coast during May and June in terms of certain synoptic features confined to *the northern hemisphere alone*, as opposed to the findings of Malurkar.

REFERENCES

ANANTHAKRISHNAN, R. *et al*. 1968. Synoptic features associated with onset of south-west monsoon over Kerala. *FMU Rep*. No. IV-18.2, 1968 Poona-5.

DE LA MOTHE, P. D. and WRIGHT, P. B. 1969. The onset of the Indian south-west monsoon and extratropical 500 mb trough-ridge patterns over Europe. *Asia. Met. Magazine*, 1969, **98** : 145.

ELIOT, J. 1890. *Handbook of cyclonic storms in the Bay of Bengal*—1890.

FLOHN, H. 1960. Recent investigations on the mechanism of the summer monsoon of southern and eastern Asia. *Symposium on monsoons of the world*, 1960, p. 75.

KOTESWARAM, P. 1960. Asian summer monsoon and general circulation—*Ibid*., 1960, p. 105.

LOCKWOOD, J. G. 1963. Winds at 200 mb over the tropics and sub-tropics during the season of monsoon change. *Met. Magazine, London*, **92** : 75.

RAMASWAMY, C. 1965. On synoptic methods of forecasting the vagaries of south-west monsoon over India and the neighbouring countries. *Symposium on Met. results of IIOE, Bombay*, 1965, p. 317.

SUTCLIFFE, R. C. and BANNON, J. K. 1954. Seasonal changes in upper conditions in the Mediterranean Middle east Area. *Proc. of 19th Gen. Assembly*, Rome 1954.

THOMPSON, B. W. 1951. Essay on the General circulation over south-east Asia and West Pacific. *Q.J. R.M.S*., 1951, p. 569.

YEH, T. C., DAO, S. Y. and LI, M. T. 1959. The absolute change of circulation over the northern hemisphere during June & October—Bolin B. *The Atmosphere and sea in Motion*, 1959, p. 249.

YIN, M. T. 1949. A synoptic aerological study of the onset of summer monsoon over India and Burma. *Jour. of Met*., **6** : 393.